The Clustering of C IV and Mg II Absorption–Line Systems

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Abstract. We have analyzed the clustering of C IV and Mg II absorption–line systems on comoving scales from 1 to 16 h^{-1} Mpc, using an extensive catalog of heavy–element QSO absorbers with mean redshift $\langle z\rangle_{\mathrm{C\ IV}} = 2.2$ and $\langle z\rangle_{\mathrm{Mg\ II}} = 0.9$. For the C IV sample as a whole, the absorber line–of–sight correlation function is well fit by a power law of the form $\xi_{\mathrm{aa}}(r) = (r_0/r)^{\gamma}$, with maximum–likelihood values of $\gamma = 1.75\,^{+0.50}_{-0.70}$ and comoving $r_0 = 3.4\,^{+0.7}_{-1.0}$ h^{-1} Mpc ($q_0 = 0.5$). This clustering is of the *same form* as that for galaxies and clusters at low redshift, and of amplitude such that absorbers are correlated on scales of clusters of galaxies. We also trace the *evolution* of the mean amplitude $\xi_0(z)$ of the correlation function from $z = 3$ to $z = 0.9$. We find that, when parametrized in the conventional manner as $\xi_0(z) \propto (1+z)^{-(3+\epsilon)+\gamma}$, the amplitude grows *rapidly* with decreasing redshift, with maximum–likelihood value for the evolutionary parameter of $\epsilon = 2.05 \pm 1.0$ ($q_0 = 0.5$). The rapid growth seen in the clustering of absorbers is consistent with gravitationally induced growth of perturbations.

1 Introduction

In a previous paper [12], Quashnock, Vanden Berk, & York analyzed line–of–sight correlations of C IV and Mg II absorption–line systems on large scales, using an extensive catalog [15] of 2200 heavy–element absorption–line systems in over 500 QSO spectra. Here, we extend that analysis to smaller comoving scales — from 1 to 16 h^{-1} Mpc — and relate the small–scale clustering of absorbers to galaxy clustering in general.

The C IV and Mg II data sample is drawn from the catalog of Vanden Berk et al. [15], using the same selection criteria as those in [12]. It consists of 260 C IV absorbers, drawn from 202 lines of sight, with redshifts ranging from $1.2 < z < 3.6$ and mean redshift $\langle z\rangle_{\mathrm{C\ IV}} = 2.2$, and 64 Mg II absorbers, drawn from 278 lines of sight, with redshifts ranging from $0.3 < z < 1.6$ and mean redshift $\langle z\rangle_{\mathrm{Mg\ II}} = 0.9$.

Unless otherwise noted, we take $q_0 = 0.5$ and $\Lambda = 0$. We follow the usual convention and take the Hubble constant to be $100\,h$ km s^{-1} Mpc^{-1}. A more detailed version of this work, including more results and outlining our maximum–likelihood method, has appeared elsewhere [13].

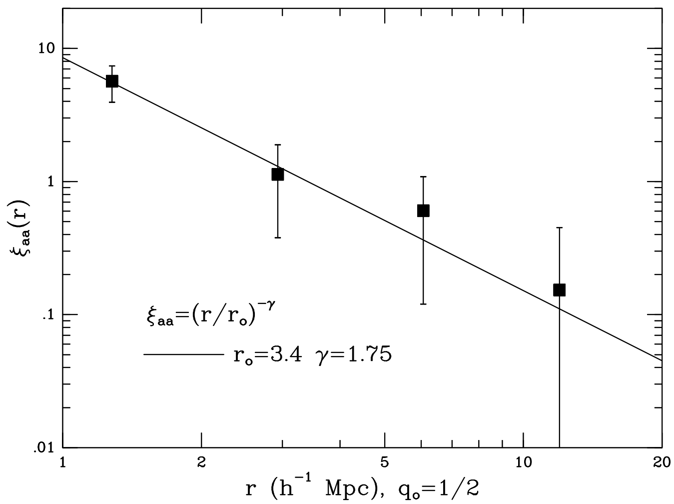

Figure 1: Line–of–sight correlation function, $\xi_{\rm aa}(r)$, for the entire sample of C IV absorbers, as a function of absorber comoving separation, r, in 4 logarithmic bins from 1 to 16 h^{-1} Mpc. The vertical error bars through the data points are 1-σ errors in the estimator for $\xi_{\rm aa}$. Also shown is a power–law fit of the form $\xi_{\rm aa}(r) = (r_0/r)^\gamma$, with maximum–likelihood values $\gamma = 1.75$ and comoving $r_0 = 3.4$ h^{-1} Mpc ($q_0 = 0.5$).

2 Form and Evolution of the Correlation Function

Figure 1 shows the line–of–sight correlation function $\xi_{\rm aa}(r)$, for the entire sample of C IV absorbers (with mean redshift $\langle z \rangle_{\rm C\ IV} = 2.2$), as a function of absorber comoving separation r from 1 to 16 h^{-1} Mpc, in 4 octaves. The vertical error bars through the data points are 1-σ errors in the estimator for $\xi_{\rm aa}$. The correlation function and error bars are computed in the same fashion and using the same selection criteria as those in [12], except that we have combined all absorbers lying within 1.0 (instead of 3.5) comoving h^{-1} Mpc of each other into a single system.

Using the maximum–likelihood method of [13], we find that, for the C IV sample as a whole, the line–of–sight correlation function is well described by a power law of the form $\xi_{\rm aa}(r) = (r_0/r)^\gamma$, with maximum–likelihood values of $\gamma = 1.75^{+0.50}_{-0.70}$ and comoving correlation length $r_0 = 3.4^{+0.7}_{-1.0}$ h^{-1} Mpc ($q_0 = 0.5$). The clustering of absorbers at high redshift is thus of the *same form* as that found for galaxies and clusters at low redshift ($\gamma = 1.77 \pm 0.04$ for galaxies [4], $\gamma = 2.1 \pm 0.3$ for clusters [8]), and of amplitude such that absorbers are correlated on scales of clusters of galaxies. It appears that the absorbers are tracing the large–scale structure seen in the distribution of galaxies and clusters, and are doing so at high redshift. The finding strengthens the case for using absorbers in probing large–scale structure.

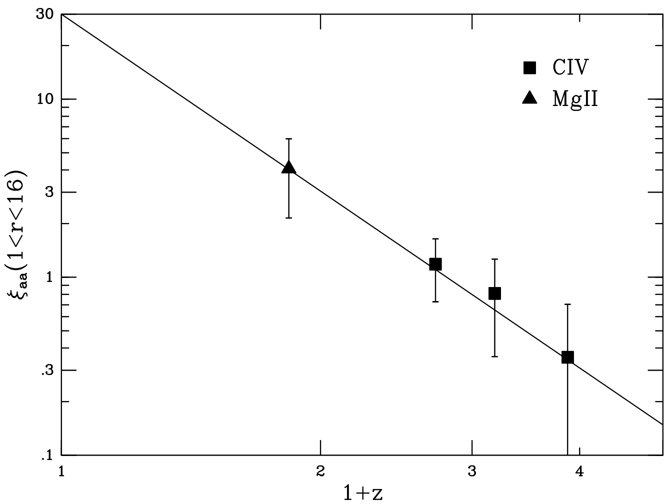

Figure 2: Mean correlation function, $\xi_0(z)$, averaged over comoving scales r from 1 to 16 h^{-1} Mpc, as a function of redshift. Shown are values for the low ($1.2 < z < 2.0$), medium ($2.0 < z < 2.8$), and high ($2.8 < z < 3.6$) redshift C IV sub–samples, as well as for the Mg II sample ($0.3 < z < 1.6$). The solid line is a maximum–likelihood fit of the form $\xi_0(z) \propto (1+z)^{-(3+\epsilon)+\gamma}$, with $\epsilon = 2.05$ and $\gamma = 1.75$ ($q_0 = 0.5$).

We have investigated the evolution of the clustering of absorbers by dividing the C IV absorber sample into three approximately equal redshift sub–samples, and comparing these to the Mg II sample. Figure 2 shows the mean of the correlation function, $\xi_0(z)$, averaged over comoving scales r from 1 to 16 h^{-1} Mpc, for the low ($1.2 < z < 2.0$), medium ($2.0 < z < 2.8$), and high ($2.8 < z < 3.6$) redshift C IV sub–samples, as well as for the Mg II sample ($0.3 < z < 1.6$). The amplitude of the correlation function is clearly growing *rapidly* with decreasing redshift.

We have used the maximum–likelihood formalism of [13] to describe the evolution of the correlation function. We have fixed γ at its maximum–likelihood value of 1.75 in our analysis, and parametrized the amplitude of the correlation function in the usual manner as $\xi_0(z) \propto (1+z)^{-(3+\epsilon)+\gamma}$, where ϵ is the evolutionary parameter [6, 7]. Using all the data sets, we find that the rapid growth is reflected in a large value for the evolutionary parameter, namely $\epsilon = 2.05 \pm 1.0$. This value is 3.3-σ from the no–evolution value ($\epsilon = -1.25$); thus, at the 99.95 % confidence level, growth of the correlation function has been detected. (These results are with $q_0 = 0.5$. With $q_0 = 0.1$, we expect our estimate of ϵ to decrease by about 1.3 .)

The rapid growth in the correlation function, and the correspondingly large value of the evolutionary parameter ($\epsilon = 2.05 \pm 1.0$) that is implied, is what is expected in a critical universe ($\Omega_0 = 1$), both from linear theory of gravita-

tional instability [9, 10], with $\xi \propto (1+z)^{-2}$ (or $\epsilon = 0.75$, if $\gamma = 1.75$), and from numerical simulations [1, 2]: For $\Omega_0 = 1$, $\epsilon = 1.0 \pm 0.1$, whereas for $\Omega_0 = 0.2$, $\epsilon = 0.2 \pm 0.1$.

Evidence for a trend of increasing clustering of Lyα absorbers (N(H I) $> 6.3 \times 10^{13}$ cm^{-2}) with decreasing redshift has been found by Cristiani et al. [3]. These authors also find a clear trend of increasing Lyα absorber clustering with increasing column density, and find that an extrapolation to column densities typical of heavy–element systems (N(H I) $> 10^{16}$ cm^{-2}) is consistent with the clustering observed for C IV absorbers [11, 14]. Our finding of growth in the clustering of heavy–element systems with decreasing redshift supports both a continuity scenario between Lyα and heavy–element systems [3], and the common action of gravitational instability.

The strong clustering that we find in the heavy–element absorption–line systems is thus not surprising, given that most of the sample consists of the strongest systems with relatively large equivalent widths (order 0.4 Å and greater), and the recent claims [3, 5] of a strong dependence of clustering strength on the column density of the systems. We do confirm that the weaker systems (equivalent widths 0.2 Å and less) are less clustered than the stronger ones, by a factor of two or so; unfortunately, most of the spectra used to assemble the Vanden Berk et al. catalog [15] are not of sufficient quality to yield a large number of weak systems.

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